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Plate VI. This gives a fair idea of the appearance of the calcium ( $H_2$ ) flocculi, though the limb is not well reproduced. The orientation is the same as for Plate III.

Plate VII, Fig. 1. The only bright flocculi that should appear in this figure are those in the neighborhood of the spot.

Plate VII, Fig. 2. The background comes out too bright, giving the appearance of bright flocculi in regions where they are not present. The only objects of this class shown by the original negative are very conspicuous in the figure.

Plate VIII, Fig. 1. This gives a fair idea of the original negative, the contrast of which is not very strong.

Plate VIII, Fig. 2. The contrast of the original is much stronger than in the case of Fig. 1, hence the bright flocculi near the spot are relatively too conspicuous. The background in the upper part of the figure is also too bright.

Plate IX, Fig. 1. The original is lacking in contrast. The region to the left of the spot should be much darker than it appears in the cut.

Plate IX, Fig. 2. This is a fairly satisfactory reproduction, though the bright flocculi should be somewhat stronger.

Plate X, Fig. 1. Except for a defect in the photograph, the bright flocculi surrounding the spot are fairly well shown. In other parts of the figure, however, the background comes out too bright.

Plate X, Fig. 2. This is a fairly satisfactory reproduction, though the background is too bright in various places.

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## SOLAR VORTICES AND THE ZEEMAN EFFECT.

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BY GEORGE E. HALE.

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In a previous paper I have described and illustrated the vortices surrounding sun-spots recently photographed on Mt. Wilson with the Snow telescope and five-foot spectrohelio-graph.<sup>1</sup> While studying the vortices, it occurred to me that the rapid revolution of electrically charged particles in the solar atmosphere should produce a magnetic field within a sun-spot (Rowland effect), if a preponderance of negative or positive ions be assumed. Such a condition might result from the emission of corpuscles by the photosphere,<sup>2</sup> or, as Professor E. F. NICHOLS has suggested to me, from centrifu-

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<sup>1</sup> "Solar Vortices," *Contributions from the Mount Wilson Solar Observatory*, No. 26, *Publications A. S. P.*, No. 121.

<sup>2</sup> J. J. THOMSON, "Conduction of Electricity through Gases," p. 164.

gal separation dependent upon differences in inertia between positive and negative ions. Light received from a spot (vortex) at the center of the Sun would then be parallel to the lines of force, and its spectrum should contain Zeeman doublets, having components circularly polarized in opposite directions. Close double lines, many of them previously observed visually in spot spectra by YOUNG and MITCHELL, had recently been photographed with the 30-foot spectrograph and tower telescope. I decided to determine whether such lines show characteristic evidences of polarization, and to search for other indications of the Zeeman effect.

I accordingly commenced work with the tower telescope and 30-foot spectrograph on June 24th. The only grating available for use with this instrument is a 4-inch Rowland, having 14,438 lines per inch, formerly used in the Kenwood spectroheliograph. Its ruled surface utilizes only a fraction of the light from the 6-inch collimator objective, but Seed "Gilt Edge" plates, sensitized by WALLACE'S process, gave fairly satisfactory spot spectra at  $\lambda 6200$  (third order) in six minutes. A Fresnel rhomb and Nicol prism were mounted in front of the slit. Beside each spot spectrum the spectrum of the photosphere on either side of the spot, or at the center of the Sun, was photographed for comparison, the path of the light, through rhomb and Nicol, being the same for the spot and comparison spectra. On each plate the same region of the spectrum was photographed several times with the Nicol set at different angles, covering a range of about  $90^\circ$ .

The components of the true Zeeman doublet, observed under these conditions along the lines of force of a magnetic field, should change in relative intensity as the Nicol is rotated. When the spot was near the limb the results were uncertain, but when it reached a point about  $45^\circ$  from the center of the Sun the appearance of the doublets seemed clearly characteristic of the Zeeman effect, the relative intensities of the two components being reversed by rotating the Nicol.

More than thirty lines showed such an effect in the region  $\lambda 6230$ – $\lambda 6241$ . In many cases these are not doublets, but there was a slight shift of the lines to the red and violet respectively, when the Nicol occupied two positions from  $45^\circ$  to  $90^\circ$  apart. This would appear to indicate that light from

the edges of these spot lines is circularly polarized in opposite directions. If so, the displacements are similar in character to those detected by ZEEMAN in his first observations of radiation in a magnetic field.

In order to determine whether the observed phenomena are to be regarded as true Zeeman effects, I have made a large number of photographs with the above-described apparatus, showing various regions of the spot spectrum from red to ultra-violet. These prove conclusively that the changes in relative intensity and position of the lines are due to the rotation of the Nicol. The results are consistent among themselves,—the Nicol in one position reducing the intensity of all the red components of doublets, while in the other position it reduces all the violet components.<sup>1</sup> Moreover, if the stronger component of a doublet appears, for example, on the red side, the single lines in the same spot spectrum are displaced toward the red, and *vice versa*.

As a great number of spot lines show these displacements, it is necessary to inquire whether they may result from unsymmetrical illumination of the grating, caused by rotation of the Nicol. This appeared improbable from the first, since the displacements were determined with respect to comparison spectra formed by solar light which passed through the rhomb and Nicol under precisely the same conditions as obtained in the case of the spot. An excellent test is afforded by many telluric lines in the red, which are not shifted by rotating the Nicol. The lines of the cyanogen fluting at  $\lambda$  3883, photographed in the fourth order, also show no displacement.<sup>2</sup> It is well known that the lines of flutings are not affected in a magnetic field.

So far as I am aware, the only means of transforming a single line into a doublet, having components circularly polarized in opposite directions, is a strong magnetic field. It thus appears probable that a sun-spot contains such a field, which gives rise to doublets and to widened lines in the spot spectrum.

<sup>1</sup> There may be a few exceptions to this rule, such as laboratory experience would lead us to expect.

<sup>2</sup> Three lines in this fluting, which I have measured on negative T 132, show a mean relative displacement of 0.0004 Angströms, corresponding to a rotation of the Nicol through 90°. This is much less than the displacement of the spot lines, and within the error of measurement.

It should be mentioned that few doublets appear on the plate in the blue and violet, while many conspicuous ones are found in the red. PRESTON and RUNGE have shown that for

lines of a given spectral series the ratio  $\frac{d\lambda}{\lambda^2}$  is a constant, but

it is also true that wide doublets have been observed in the more refrangible region of metallic spectra. Why these do not appear in spots, if a magnetic field sufficiently powerful to produce red doublets is present, cannot now be answered.

The separation of the components of many doublets, as measured on the photographs, ranges from 0.018 to 0.216 Ångströms. All of these lines, and many of those which are merely shifted by rotation of the Nicol, will be studied in our laboratory with the aid of a large Du Bois magnet, which is fortunately available. In this work the Zeeman effect will be observed parallel and normal to the lines of force, and at certain intermediate angles, corresponding to various positions of spots on the Sun. It is interesting to note in this connection that lines which appear to be double in some of our spot photographs are triple in others. MITCHELL illustrates an excellent case of this sort (observed visually) in the *Astrophysical Journal*, Vol. XXIV, p. 79,<sup>1</sup> where a line which is double across the umbra and one side of the penumbra of a spot is triple across the opposite side of the penumbra. This may perhaps be due to the fact that the line of sight passed through an inclined vortex, parallel to the lines of force in one case and normal to them in the other.

These results suggest many possible subjects of investigation, some of which I am preparing to attack, in conjunction with our daily photographic observations of the solar vortices. The direction of the whirls, whether right-handed or left-handed, is a matter of prime interest now under examination.

The question naturally arises whether terrestrial magnetic storms, which are known to be closely related to sun-spots, can be caused, directly or indirectly, by solar magnetic fields. If the work now in progress should establish the existence of such fields, it would become necessary to make systematic records of their areas, intensities, and polarities, in all parts of the

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<sup>1</sup> This paper contains many visual observations of the double lines in spot spectra.

Sun, for comparison with simultaneous records of terrestrial magnetism, before definite conclusions could be drawn.

If spots like those on the Sun are most numerous in the later stages of a star's development, it is conceivable that they may cover a large part of the disk of certain red stars. With sufficient dispersion it might therefore become possible to detect Zeeman doublets in the spectra of these objects. As a fixed spectrograph of great power is being provided for use with our 60-inch reflector, now nearing completion, I hope to make the necessary tests this autumn.

A more complete account of the sun-spot work, giving measures of the doublets and various other data, will soon be published in the *Astrophysical Journal*.

MT. WILSON SOLAR OBSERVATORY, July 3, 1908.

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## PLANETARY PHENOMENA FOR SEPTEMBER AND OCTOBER, 1908.

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BY MALCOLM MCNEILL.

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### PHASES OF THE MOON, PACIFIC TIME.

First Quarter... Sept. 3, 12 <sup>h</sup> 51 <sup>m</sup> P.M.	First Quarter... Oct. 2, 10 <sup>h</sup> 14 <sup>m</sup> P.M.
Full Moon..... " 10, 4 23 A.M.	Full Moon..... " 9, 1 3 P.M.
Last Quarter... " 17, 2 33 A.M.	Last Quarter... " 16, 7 35 P.M.
New Moon.... " 25, 6 59 A.M.	New Moon.... " 24, 10 47 P.M.

The autumnal equinox, the time when the Sun crosses the equator from north to south, and autumn begins, comes on September 23d, at 3<sup>h</sup> A.M., Pacific time.

*Mercury* will not be in good position for observation during September and October. It passed superior conjunction on August 20th and became an evening star, but as its distance from the Sun increases its motion also carries it far to the south of the Sun, even more than is normal for eastern elongations in the autumn. It reaches greatest east elongation on October 4th. This distance, 25° 34', is considerably greater than the average greatest elongation, but the planet is at this time more than 11° south of the Sun. So the planet does not remain above the horizon as much as an hour after sunset,